High sensitivity sensor for moderate pressures

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High sensitivity sensor for moderate pressures

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The metal–insulator transition of $(V_{0.99}Ti_{0.01})_2O_3$ is marked by dramatic changes in the electrical resistivity and the magnetic susceptibility, with a linear pressure variation of -6.06 K/kbar for $P \leqslant 15$ kbar. We propose its use as the sensing element of a manometer in applications where the superconducting transition of soft metals has been traditional. © *1996 American Institute of Physics.* [S0034-6748(96)03402-5]

The standard technique for measuring pressure in a BeCu hydrostatic pressure cell is to insert a small piece of Pb or Sn and to monitor its superconducting transition temperature $T_c(P)$. These elements are chosen for their large $T_c(P)$, of order 40 mK/kbar.[1] We report here an alternative material for use as the sensing element of a manometer, with a response more than 100 times greater than that of the best superconducting elements. Moreover, its response is linear with pressure up to 15 kbar, with easily measured signatures in both the resistivity and the magnetic susceptibility.

The material of choice is $(V_{1-x}T_x)_2O_3$, which for $x=0.01$ undergoes a spectacular first-order metal–insulator transition at $T_{MI}=141$ K. A jump in the resistivity of more than four orders of magnitude at T_{MI} is accompanied by a coincident magnetic transition from paramagnetic metal to antiferromagnetic insulator. Single crystals of this classic Mott–Hubbard system were grown from melt by the Reed tri-arc technique. Thin slices cut from crystals of typical size 1 cm^3 then were annealed in a H_2 atmosphere until rendered stoichiometric.[2] Four-probe resistivity measurements using a standard lock-in technique were performed on several different batches of crystals to ensure sample homogeneity and repeatability. Hydrostatic pressure was applied to samples of typical dimensions $(1\times1\times3)$ mm^3 with a BeCu-WC piston-anvil self-locking pressure clamp,[3] using silicone oil as the pressure medium and the T_c of lead as the pressure standard.

We plot in Fig. 1 the resistivity $\rho(T)$ for $(V_{0.99}Ti_{0.01})_2O_3$ at a series of pressures P. The temperature hysteresis, reflecting the first-order nature of the transition, remains constant at 11 K at all P; for clarity only the data taken upon cooling are shown. The resistivity decreases slightly with decreasing temperature in the metal, increases abruptly at the metal–insulator transition, and assumes an activated form in the insulator. The four decades jump at T_{MI} moves quickly to lower temperature with increasing pressure, and it is tracked by a sharp drop in the magnetic susceptibility of order 30%.[3]

We summarize in Fig. 2 the pressure variation of the metal-insulator transition temperature obtained on cooling. Here, T_{MI} has been defined by the logarithmic midpoint of the jump in $\rho(T)$. The pressure scale has been adjusted for the effects of differential thermal contraction of the diverse materials in the clamp[4,5] following the data of Thompson.[5] The solid line is a least-squares fit to a linear pressure dependence of the transition temperature, with a slope of -6.06 K/kbar and an intercept of 141 K. Above 15 kbar there are strong deviations from linearity, and for $P>17$ kbar the metallic state is stabilized at all T.

Pure vanadium sesquioxide similarly can serve as a sensitive pressure sensor, with an active range up to 20 kbar. However, T_{MI} is not strictly linear in P because of a different mechanism for gap formation in the insulator.[3,6] Furthermore, particular care is required to prepare stoichiometric crystals for bulk resistivity measurements as they are prone to the shorting effects of a damaged surface layer.

We have shown (Fig. 2) that crystals of $(V_{0.99}Ti_{0.01})_2O_3$ are two orders of magnitude more sensitive to pressure changes than Pb or Sn. The metal–insulator transition is depressed by more than 6 K/kbar; the response is linear up to 15 kbar; the sensor can be monitored electrically or magnetically; a calibration of the pressure cell can be performed well above liquid-helium temperatures (above liquid–nitrogen

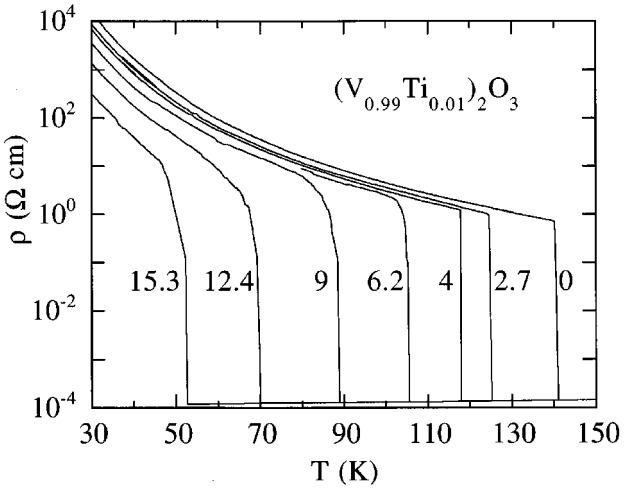

FIG. 1. Electrical resistivity ρ over eight decades vs temperature T through the metal–insulator transition of Ti-doped vanadium sesquioxide on cooling at a series of indicated pressures in kbar.

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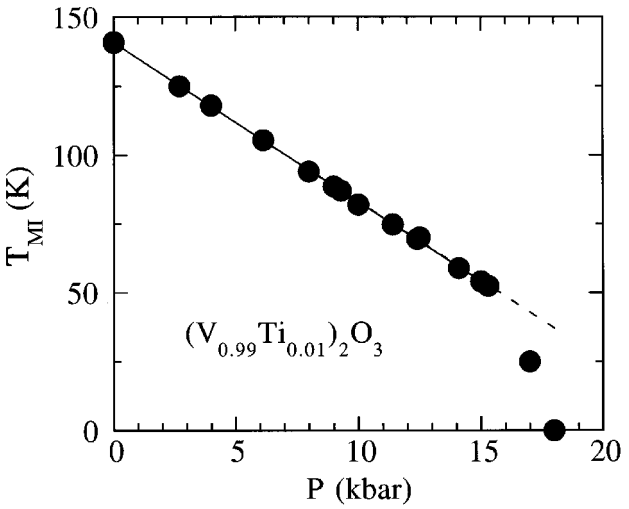

FIG. 2. Variation of the metal–insulator transition temperature T_{MI} with hydrostatic pressure P on cooling. The solid line is a linear least-squares fit with slope −6.06 K/kbar and intercept 141 K.

temperatures for most of the sensor's range). A few cautionary details should be noted: (i) The crystals can crack if thermally cycled without any pressure applied. This is the result of a volume change at the first-order metal–insulator transition. Pressures as small as a few tenths kbar suppress the cracking. (ii) The crystal surface should be sanded before electrical leads are applied. Silver paint contact resistances then should not exceed a few Ohms in the metal, permitting a clear resolution of the jump in $\rho(T)$ even in a two-probe configuration. (iii) Given the large (11 K) thermal hysteresis of the transition signature, it is important to keep track of the thermal history.

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